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Implementing a Solar Power System for a High School in Tonga

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Executive Summary

Engineers Without Borders New Zealand (EWBNZ) is an organisation of professional and student engineers who aim to use their skills to provide humanitarian aid.

In 2008 the University of Canterbury chapter of EWBNZ collaborated with EcoCARE Pacific Trust on the Tonga Renewable Energies Project. Upon the recommendation of the Tongan Minister of Education, a group of students and academics visited Vava'u High School in Vava'u, Kingdom of Tonga. Based on observations from this trip the team decided that a grid-tied solar photovoltaic system was the best renewable energy system for the school due to practical and cultural considerations.

The team returned to the school in November 2009 and successfully installed a 1.44kW solar photovoltaic system. The system has already provided a noticeable decrease in the school's electricity bill and has survived a tropical cyclone.

The power quality of the island's electricity supply was analysed and found to be reasonable although of a lower standard than what would be expected in New Zealand. The power usage at the school was also analysed and it was found that most of the loads on the school supply were from power electronic devices and caused significant current harmonics.

Energy conservation measures for computer use were recommended that could provide significant financial savings for the school.

Voltage variation and surges are likely to have destroyed most of the power computers at the school. The team managed to assemble three computers from the parts of about 30 computers. Edubuntu Linux version 9.10 was installed on some of these computers for demonstration purposes. The IT teacher was happy with the solutions that Linux provided and desired to install it on computers they will obtain in the future.

Overall, the project was a success for EWBNZ. The Canterbury chapter demonstrated the ability to implement an overseas project and learned some valuable lessons in doing so. The EcoCARE Pacific Trust and the Tongan Ministry of Education were also happy with the project outcomes.

Sponsors

The Vava'u High School Renewable Energies Project was kindly sponsored by the following organizations:

Acknowledgements

In addition to the above sponsors a wide range of individuals committed countless hours to assist in the development and successful implementation of this trip. Engineers Without Borders NZ would like to thank Jim Palmer Jim Palmer of James A Palmer Ltd and Rotary International, Julian Martel of Fresh Energy, Hamish Littin of Elemental Energy, Hadleigh Jones of EcoValue, David Bonniface of Bonniface Consulting, Ken Smart of the University of Canterbury Electrical and Computer Engineering Department for sharing their knowledge and experience.

Special thanks must go to the people of Tonga who assisted with the project, particularly Vava'u High School and the Tongan Ministry of Education for their help and warm hospitality.

Introduction

Engineers Without Borders New Zealand (EWBNZ) is an organisation of professional and student engineers who share a vision of confronting the global challenges of poverty, sustainable development and social inequity by undertaking projects that will directly improve the quality of life in communities within New Zealand and in the South Pacific region. The organisation was established by the initiative of students at the University of Canterbury and the University of Auckland in 2008.

The Tonga Renewable Energies Project began in June 2008 from collaboration between EWBNZ and the EcoCARE Pacific Trust, an organisation that has provided a variety of aid services to Tonga and is based at the University of Canterbury. The Tongan Minister of Education put forward Vava'u High School on the island of Vava'u, Kingdom of Tonga as being a good candidate for an aid and development project. The Canterbury chapter of EWBNZ took up the suggestion and sent over a team of five students with an academic supervisor to the high school in November 2008.

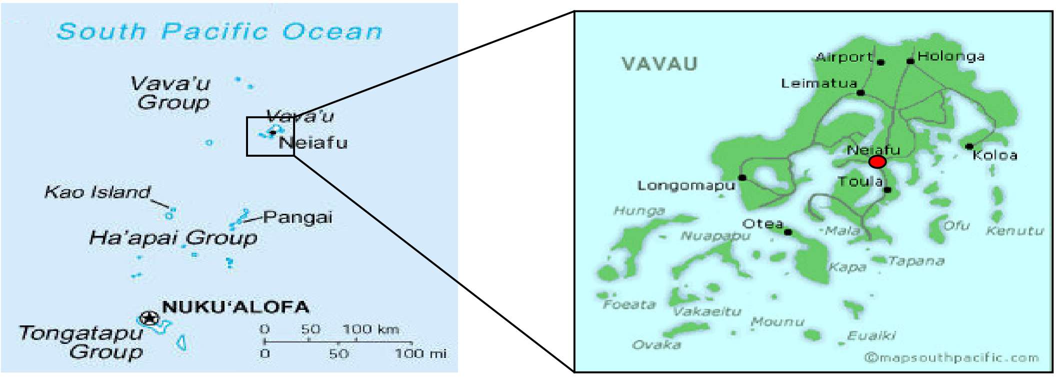

Figure 1 – Location of Vava'u High School in the town of Neiafu, Vava'u

On this preliminary trip the team performed an energy audit of the school, visited the electricity generation site and investigated the possibilities for installing some type of renewable energy system. Upon returning to New Zealand and analysing all the data collected, the team determined that a grid-tied solar photovoltaic (PV) system would provide a significant benefit to the school.

As this was the first project performed by the EWBNZ Canterbury chapter, the student-led team encountered a number of difficulties, the greatest being the challenge of obtaining funding during an economic recession. Through the generosity of a variety of sponsors and the assistance of suppliers, tradesmen and professionals, a solar PV system was designed, obtained and sent to Tonga in November 2009.

A team of six students, two academics, an EcoCARE Pacific Trust trustee and a New Zealand registered electrician then travelled to the school and installed the system. The team also provided assistance with the restoration of the computer suite and suggested ways in which electricity and water usage could be conserved.

This paper provides information about the solar PV system, the school power usage assessment and the computer suite restoration. The paper is aimed to provide insight about the challenges and considerations required for providing technological aid in a Pacific Island nation.

Solar PV System

A range of renewable energy systems were initially investigated and it was initially anticipated that electricity generating wind turbines would be used. However, after the preliminary trip to the high school a number of practical considerations were noted and an understanding of Tongan culture was developed. After much discussion it was decided that a grid-tied solar PV system was the most appropriate renewable energy system and would provide a significant benefit to the high school. The major considerations were:

- It was observed that little maintenance and upkeep was performed around the school. This was probably due to a lack of funds and expertise combined with some cultural attitudes. Consequently, a system with minimal maintenance was desired. A tourist operator on the island had a hybrid wind turbine and solar PV system with a battery bank. Over two and a half years of operation he had experienced a number of problems with the wind turbine and the battery bank but no problems with his roof-mounted solar PV panels.

- It was observed that there were no adequate refuse disposal facilities on the island. If a battery bank were to be used, there could be some environmental issues related with their eventual disposal.

- The time of electricity generation coincided well with the time of energy usage at the school such that energy storage was not required. Also, funding was limited such that a simple system with no expensive batteries was desirable.

- The electricity on the island is produced by diesel generators. Due to transport costs and the increasing price of diesel, electricity costs for the school are very high compared to New Zealand and fluctuate a lot. The high cost of electricity coupled with greater solar insolation received in Tonga makes solar PV a more economical option than in New Zealand.

The system consisted of eight 180W monocrystalline PV panels that were mounted on a north-facing roof using an aluminium mounting system. The panels were connected in series to a grid-tied inverter which fed into a single phase on the school’s main switchboard. The system electrical schematic is shown in Appendix A.

Figure 2 – The solar photovoltaic panels being installed on roof

The system size of 1.44kW was chosen based on the amount of funding obtained and also that it was predicted to provide all of power requirement for the chosen phase with minimal electricity fed back into the grid. A renewable energy modelling program was used to model the system and yielded the following results shown in Table 1.

Table 1 – Estimated annual energy production

	Energy (kWh/year)	**Cost ($TOP/year)**
Total output	2142	$1789
Output consumed at VHS	2031	$1696
Output fed back into grid	111	$92.7

The installation of system was successfully carried out and it conforms to all of the appropriate New Zealand and Australian standards. Feedback from a staff member at the school suggests that the school electricity bill has noticeably decreased since the system was implemented. The system has also survived through a tropical cyclone that hit in February 2010.

Vava'u High School Power Usage Assessment

The school is connected to the main grid and runs on a three-phase, 240V, 50Hz system. A three-phase power quality analyser was installed on the main incoming line in the main school switchboard and three-phase voltages, currents, power, harmonics and other indicators were recorded. In addition, after the PV panels and inverter were installed, a single phase power quality analyser was installed to monitor the single phase inverter output. Another power meter was used to check various feeders around the school site to trace power usage at various times of the day.

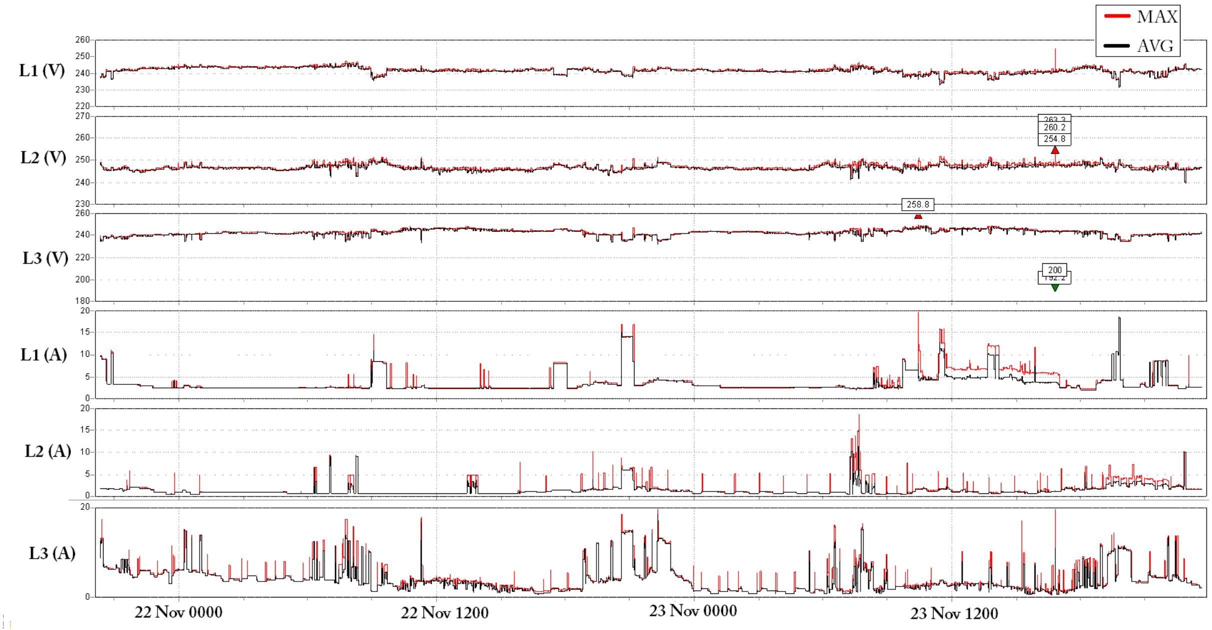

Figure 3 – Three-phase voltage and current records at main switchboard

The voltage was found to be slightly unbalanced from Figure 3 as the current measured on each phase was different. This is to be expected for small systems. The voltage waveform indicates the voltage profile varied between 230Vrms and 250Vrms on each phase, with some surges of up to 260Vrms. In addition, regular current spikes of up to 60A were noted, likely from a motor start up. Many of the short pulses of current in the graph resulted from power tools used in the installation of the PV panels, and other regular spikes are likely to correspond to fridges. It was thought that many of the high current (15A) blocks lasting for several minutes to an hour were staff house heat pumps or a suspected large washing machine (possibly heating water). However, the bulk of the continuous current draw on Line 1 was traced to the 6-8 school office computers. Line 3 current was mostly to the staff housing (lighting, TVs etc).

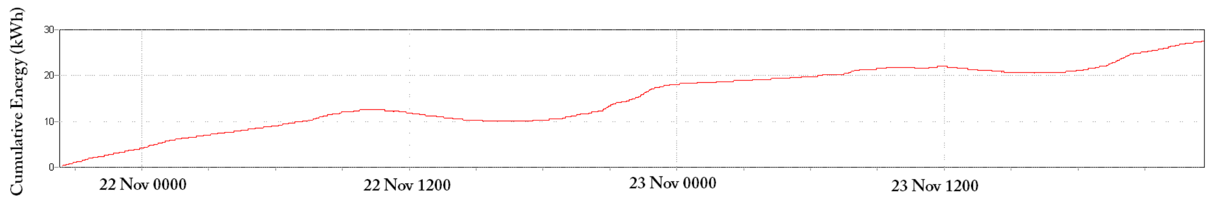

Figure 4 – Cumulative energy record for Line 3

The inverter was connected to the Line 3 phase and the PV panel power injection is seen twice in Figure 4 above which shows the cumulative energy decreasing twice. The dip curves are characteristic of the amount of sunlight hitting the PV panels as the sun moves across the sky.

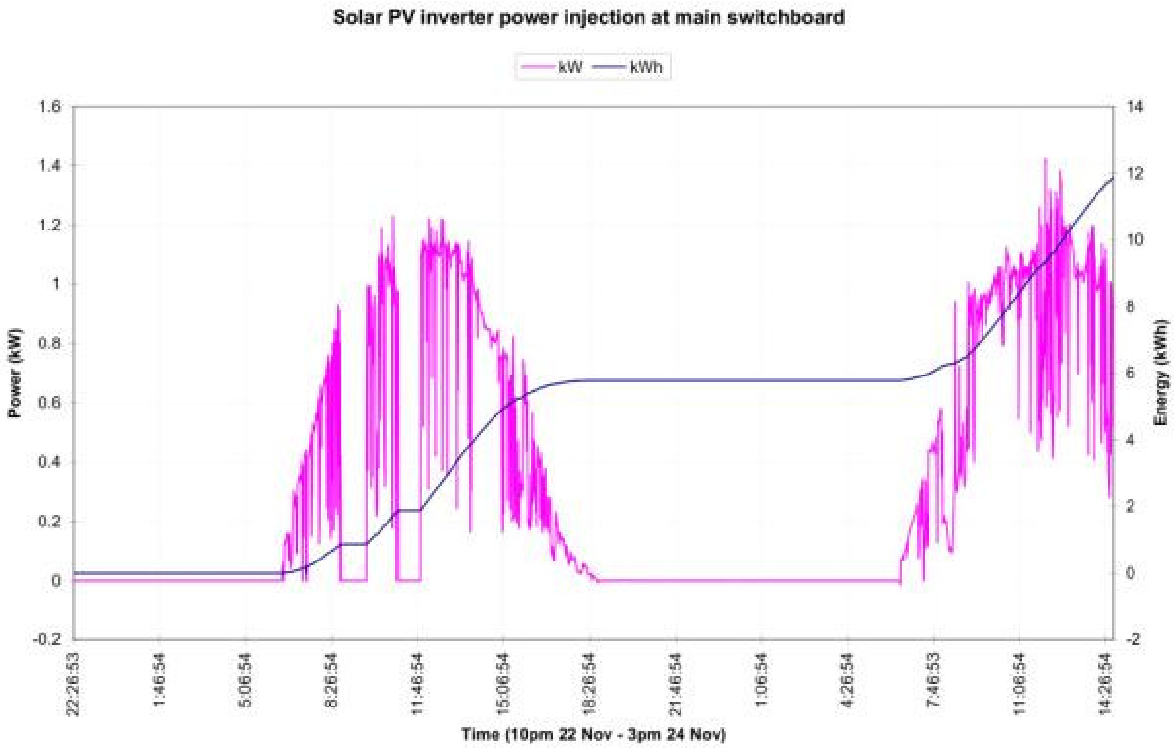

Figure 5 – Inverter power injection and cumulative energy record

The single phase recording of the PV panel inverter is given above in Figure 5. The multiple drops in power production are most likely due to passing cloud cover. Approximately 6-8 kWh was being produced daily by the PV panels. This agrees well with the results obtained from modelling the system.

Figure 6 – Frequency Stability

Although voltage stability varied significantly, frequency stability was considered to be reasonably good for a small island power system. However, there were some step changes as can be seen in Figure 6 above. The PV inverter was set to operate with a wider voltage and frequency tolerances before self-disconnecting than is used in New Zealand. It was thought that this was appropriate for the Vava'u power system. Voltage harmonics were typically 4-6%, dominated by the 5th harmonic. This is higher than NZ levels, but is unlikely to cause problems unless they increase further. This characteristic is typical of many power electronics devices (computers, cell phone chargers, CFLs, TVs etc) being connected to the power system. Significant current harmonics of up to 60% show that most of the loads in the school are power electronic devices.

Most of the office computers are fed from Line 1 (red phase) and had been left running continuously, 24 hours a day, with screens still on. Power measurements were made for each of the office computers as follows in Table 2a**Error! Reference source not found.**.

Table 2 – Computer Usage Cost Analysis

Computer Power Usage Cost

	Amps	Power	kWh/Day	$TOP/ Day	kWh/Year	$TOP/ Year	Potential Savings
2x Staff (together)	0.66	156.42	3.75	$ 3.26	1,370.24	$ 1,190.60	$ 793.65
Library	0.33	78.21	1.88	$ 1.63	685.12	$ 595.30	$ 396.83
Library laptop	0.17	40.29	0.97	$ 0.84	352.94	$ 306.67	$ 204.43
Principal's office	0.37	87.69	2.10	$ 1.83	768.16	$ 667.46	$ 444.93
Deputy principal's office	0.6	142.2	3.41	$ 2.97	1,245.67	$ 1,082.36	$ 721.50
Deputy principal's office	0.11	26.07	0.63	$ 0.54	228.37	$ 198.43	$ 132.28
Admin room	0.41	97.17	2.33	$ 2.03	851.21	$ 739.62	$ 493.03
Total	**2.65**	**628.05**	**15.07**	**13.10**	**5539.97**	**4780.99**	**3187.01**

While these amounts are approximate, this is a significant amount of electricity use for the school. Attempts were made to enable power saving settings on these computers with some success, but the lack of administrator passwords prevented some computers from being changed.

It was recommended that a new school policy be enacted requiring office computers to be turned off when not in use, especially overnight and on weekends. The energy savings would likely be more than the total energy output of the newly installed solar PV panels. The same power savings policy should be applied to any computers in the student computer lab, with suitable power management settings being enabled on these computers. It was noted that a majority of power sockets in the student computer lab came from Line 3, and it was for this reason that the PV inverter was connected to this phase. It is expected that the student computer lab will be in operation during the day which is when the PV panels are generating.

Computer Lab Restoration

The preliminary trip to Vava'u High School in November 2008 found that while the student computer lab had approximately 30 desktop computers, only 3 computers worked sufficiently to be useful. It was understood a good internet connection was available to the school. There were reports of missing computer mice and computer viruses present, which had effectively rendered the lab non-functional. On the November 2009 visit, the intention was to restore the desktop computers in the student computer lab to a useful state by fixing hardware issues, installing Edubuntu Linux and supplying additional second-hand optical mice. Having usefully functioning computers would allow classes of students to become familiar with computers, software and various computing concepts. In addition, the internet access would allow search and exploration for knowledge, and communication with the larger world. Obviously, a functioning computer is required before the internet can be accessed.

Upon arrival in November 2009 the computer lab was found to be in a much worse state than expected. No computer lab lessons were being held. Only one very old computer was working, with several of the newer computers having been pulled apart by the IT teacher in an attempt to mix together parts to get at least some computers working. Approximately 7 computers were within 6 years old, the rest being of an old enough age to have ISA motherboard slots. Only two mice were present in the lab, and many keyboards had missing keys.

Figure 7 – Computer lab with non-functioning computers spread around the outer walls

Typical computer lab problems reported by the IT teacher were:

- Power supply problems, surges/dips blowing computer power supplies and motherboards.
- Lots of students having flash memory sticks which transferred viruses around.
- Mice and keyboards being stolen. The teacher is not always present in lab when students are there.
- Students changing Microsoft Windows settings, which made the computer inoperable.

The IT teacher had the following wish-list for the computer lab and the following solutions were provided:

- Being able to share files between class PCs, rather than using memory sticks.
    - Rather than using a dedicated server which increases lab complexity, using 'Shared folders' in Ubuntu worked sufficiently well.
- To open a Microsoft Word file with formatting intact. Part of the school curriculum is to prepare documents which are sent away from the school for external marking.
    - OpenOffice is very good but not perfect at Word file formatting. However, using the 'PDF export' option in OpenOffice seemed to be acceptable.
- Prevent computer settings changing.
    - By using Linux, the core operating system files would not be able to be altered. If user accounts are damaged, they can be easily deleted and replaced.
- Stop students surfing internet when they should be doing school work. The IT teacher presently just unplugs network cable.
    - Without setting up a complex dedicated network router, it was suggested that this technique be continued.

Three computers were assembled from the parts of several other computers. Typical faults in the other computers were motherboards beeping and refusing to start, blown power supplies (mains voltage was noted to be often over 250 Volts AC with some wild voltage swings), incompatible and missing memory sticks, faulty hard drives, expansion cards not correctly seated, and incompatibility in parts eg. SATA hard drive needed but not available. The rest of the computers were too old to be considered worthy of fixing. The donation of 12 optical computer mice was highly appreciated, and solved the problem of existing mice balls being stolen and mice roller wheels getting dirty.

Edubuntu Linux version 9.10 was installed on the newly working computers and demonstrated to the IT teacher and principal. The IT teacher had been in Japan for at least 2 years and had briefly used Linux before, but was not familiar with it enough to install it himself (the internet connection was also too slow for downloading Linux install CDs). After showing OpenOffice, drawing programs and internet browsing, the IT teacher and principal seemed very interested in using Linux. In general, Linux installed extremely well without further configuration needed. An 'administrator' account was created on each computer, along with a general use 'student' account. Four Linux install CDs were given to the school.

A fairly comprehensive range of documentation was printed (3 copies) and passed onto the IT teacher, which covered explanations of Linux, why it is useful, installation, use and technical maintenance. It was thought that by the time a reader had looked through this material, they would have a good appreciation of the basics of Linux use. Some A3 sized Linux posters were also printed and given to the lab.

The IT teacher mentioned that 30 new computers were expected to be donated to the school by an ex-student in July 2010. As a result, it was not felt that fixing many existing computers was needed. The IT teacher was very interested in installing Linux on these new computers when they arrived, possibly in dual-boot mode. Due to the poor mains power quality, it was suggested that using an Uninterruptable Power Supply (UPS) or other power conditioning equipment would be beneficial to prevent burnt computer power supplies and blown motherboards.

Conclusions

A solar PV system without energy storage was deemed to be the best renewable energy system for Vava'u High School in the Kingdom of Tonga. The EWBNZ team successfully installed a grid-tied solar PV system which has already provided a tangible benefit to the school and survived a tropical cyclone.

The power quality at the high school was analysed and found to be reasonable although of a lower standard than what would be expected in New Zealand. Most of the loads on the school supply were found to be from power electronic devices. Energy conservation measures for computer use were recommended that could provide significant financial savings for the school.

Voltage variation and surges recorded provided an explanation of why the power supplies of a number of computers had been destroyed. Three computers were assembled from the parts of about 30 computers and Edubuntu Linux version 9.10 was installed on them. The IT teacher was happy with the solutions that Linux provided and desired to install it on computers they will obtain in the future.

Appendix A – System Schematic